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REE CONCENTRATIONS AND ANOMALIES IN THE ENSTATITE OF UNEQUILIBRATED ENSTATITE CHONDRITES. W. Hsu and G. Crozaz, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, St. Louis MO 63130, USA.

Previous REE analyses of unequilibrated enstatite chondrites (UECs) have shown that the REE patterns of enstatite grains tend to be mirror images of those of oldhamite, the major REE carrier in UECs [1]. A detailed study of REE concentrations in Qingzhen (EH3) has also demonstrated that enstatites with red and blue cathodoluminescence (CL) have REE patterns that cannot be distinguished, and therefore these two types of enstatite must have been formed by similar processes [2], contrary to a suggested model [3].

We have extended our ion microprobe study of enstatite to five UECs: Qingzhen (EH3), Yamato-691 (EH3), Indarch (EH4), MAC 88136 (EL3), and EET 90299 (EL3). The new and more extensive set of data confirms our previous conclusions [2]. In addition to the negative Eu and Yb anomalies that characterize many enstatite grains, we also observed enstatite grains with a negative Sm anomaly that is always associated with a negative Yb anomaly. We analyzed both red and blue CL enstatite in chondrules as well as single grains. The absolute REE concentrations vary from measurement to measurement. However, there are no REE patterns or abundances that uniquely characterize either the CL color or the mode of occurrence of enstatite. Three REE patterns are commonly observed in both red and blue CL enstatite. Pattern I is a relative flat REE pattern (with a slight increase from LREEs to HREEs). Pattern II is similar to Pattern I, but with negative Eu and Yb anomalies (and sometimes only a Eu anomaly) and a more pronounced increase from the LREEs to the HREEs; this is the most common REE pattern for enstatite. Pattern III is much steeper, with an estimated CI-normalized Lu/La ratio of 500 and very low REE abundances (0.001× CI to 0.1× CI). It is the only pattern that is compatible with what is known about the partition of REEs in low-Ca pyroxenes crystallizing from a melt.

In UECs, enstatite usually contains numerous tiny inclusions of albitic and sulfidic compositions [4]. By monitoring the Ca and S signals throughout the measurements, we ascertained that the enstatite patterns were not due to the presence of oldhamite inclusions. Lanthanum and Y abundances were found to correlate positively with Na, Al, and Ca, suggesting that the REE concentrations in enstatite are strongly controlled by the amount of trapped melt. Repeated analyses of the same enstatite grain yield similar REE patterns but with different REE abundances, indicating that the inclusions are heterogeneously distributed. Barred enstatite chondrules, because of their faster cooling, seem to have trapped larger amounts of melt. REE Pattern III, characterized by very low abundances, is associated with very low Na, Al, and Ca concentrations.

Evaporative loss of Eu, Yb, and sometimes Sm during enstatite crystallization may be responsible for their depletions. Under the highly reducing conditions during formation of enstatite chondrites, Yb, Eu, and Sm (listed here in the order of decreasing volatility [5]) are relatively volatile in comparison with the other REEs. Although it is likely that these three REEs were lost from the melt, the Eu depletions are probably partly due to igneous fractionation. Under reducing conditions, Eu tends to be predominantly divalent; with a larger radius than the neighboring trivalent REEs, it will have a stronger tendency to stay in the melt.

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FORMATION OF CHONDRITES IN A THICK DYNAMIC REGOLITH. S. Huang, D. W. G. Sears, and P. H. Benoit, Cosmochemistry Group, University of Arkansas, Fayetteville AR 72701, USA.

In a companion abstract we have proposed that chondrules formed as the products of energetic impacts in a very thick dynamic dust layer of an accreting asteroid-sized object and that the various chondrule groups, and thus chondrite classes, formed by variations in the number and intensity of impacts [1]. We here argue that in such a dust layer there was probably a steady flow of volatiles and that on occasion conditions may have resembled those of a fluidized bed in which density and size sorting produced the metal-silicate fractionation and chondrule size distributions observed among the chondrites.

The existence of a temporary atmosphere is suggested by the elemental and isotopic abundance patterns observed in chondrules [2–4]. The atmosphere may have been permanent, but was probably transient, consisting of water and other volatiles from the parent body most probably produced during accretion and chondrule formation [5]. It seems unlikely that such an atmosphere would be cosmic in composition and there are experimental reasons for suspecting that the H/O ratio was many orders of magnitude below cosmic [6] and the P(Na) was much higher than expected for gases of cosmic composition [7]. The requirements for minimal fluidization are determined by equating the upward drag force of the escaping volatiles (which is dependent on the Reynold's number, R_e, which in turn depends primarily on the flow rate of the gases) and the downward gravitational force on the particles [8]

$$\frac{1.75R_e^2}{\varepsilon^3\phi}+\frac{150(1-\varepsilon)R_e}{\varepsilon^3\phi^2}=\frac{d^3\rho_g(\rho_s-\rho_g)g}{\mu^2}$$

where ε is the void fraction under minimum flow conditions (typically 0.6), ϕ is the sphericity (also typically 0.6) and d the diameter of the particles (typically 100 μm), ρ_g and ρ_s are the densities of the gas (calculated assuming an ideal H_2O gas) and solids (3.2 g/cm^3), μ is the viscosity of the gas (typically 1.8×10^{-4} poise), and g is the acceleration due to gravity. We calculate that most asteroids smaller than a few hundred kilometers should be capable of producing a sufficiently high flow rate of volatiles to produce fluidization.

It seems to us that a thick dynamic dust layer on an asteroid-sized body into which material is falling energetically would create an environment in which all the major properties of chondrules and the chondrite classes are readily explicable. The different lithophile-element patterns and the redox states reflect the chondrule-forming process, while the siderophile-element fractionations and size sorting reflect density and size separations in an environment resembling a fluidized bed. Density separations are rapid in a fluidized bed, with a relatively pure high-density layer forming at the bottom and a less pure low-density layer forming at the top [8,9]. The size sorting experienced by several chondrite classes also infers conditions resembling those of a fluidized bed [10,11]. Thus we suggest that fluidization was especially important on the EH and EL parent objects, the EH chondrites being from the metal-enriched deep layer and the EL chondrites being from the metal-depleted surface, while on the ordinary chondrite parent object the depth increased along the series LL, L, and H. Except perhaps for CO and CV chondrites, carbonaceous chondrites generally suffered little density separation. The extent of presumed fluidization seems to decrease with present volatile contents of the classes, consistent with the loss of volatiles during fluidization from parents of generally similar original composition.

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Mg AND Ti ISOTOPES IN PRESOLAR Al_2O_3. G. R. Huss, A. J.

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Previously, we reported O isotopic compositions and initial $^{26}Al/^{27}Al$ ratios for two presolar Al_2O_3 grains, Orgueil B and Bishunpur B39 [1–3]. In Orgueil B, $^{17}O/^{16}O$ is about twice the solar value but $^{18}O/^{16}O$ is normal. In B39, $^{17}O/^{16}O$ is ~7× higher than solar and $^{18}O/^{16}O$ is 0.6× the solar value. Spectroscopic observations of red giant stars show similar O compositions [4], which result when material that has experienced partial H burning is mixed into the stellar envelope by the first dredge-up [3,5]. The $^{17}O/^{16}O$ ratios indicate that Orgueil B originated around a star of ~1.5 $M_\odot$, while B39 formed around either a ~2 $M_\odot$ or 4–7 $M_\odot$ star [3,5]. Both grains formed with $^{26}Al/^{27}Al$ ratios of ~10^{-3}. Aluminum-26 is produced in the H shell after core H burning has ceased and first dredge-up has occurred. It is spread through the envelope by the third dredge-up, which occurs in low- and intermediate-mass stars as a series of mixing events driven by thermal pulses in the He shell. In intermediate-mass stars (3–8 $M_\odot$), ^{26}Al can also be brought to the surface by the second dredge-up, which occurs at the end of core He burning.

We have measured Ti isotopes by ion probe in Orgueil B and Bishunpur B39, looking for evidence of He-shell nucleosynthesis. A more precise $^{25}Mg/^{24}Mg$ value was also obtained for Orgueil B. Our results are plotted as delta values relative to the solar ratios in the Fig. 1. In Orgueil B, ^{25}Mg is significantly enriched relative to ^{24}Mg, and ^{46}Ti, ^{47}Ti, ^{49}Ti, and ^{50}Ti are enriched relative to ^{48}Ti, as expected from s-process synthesis in AGB stars [6]. In contrast, B39 has normal ratios within uncertainties (a large Cr interference rendered ^{50}Ti unmeasurable). Oxygen isotopes and ^{26}Al show that both grains are circumstellar condensates. While such grains might interact later with material of solar composition, either in space or in the meteorite, the presence of very large ^{26}Mg and ^{17}O excesses shows that such interaction did not take place. We thus interpret the isotopic compositions of these grains in terms of mixing in stellar envelopes.

Stars of ~1.5 $M_\odot$ do not experience second dredge-up [5], so the ^{26}Al in Orgueil B must have been mixed outward during third dredge-up, which also supplies He-shell (s-process) material to the envelope. The size of the isotopic shifts in Ti and Mg suggest that Orgueil B contains ~5–10× more

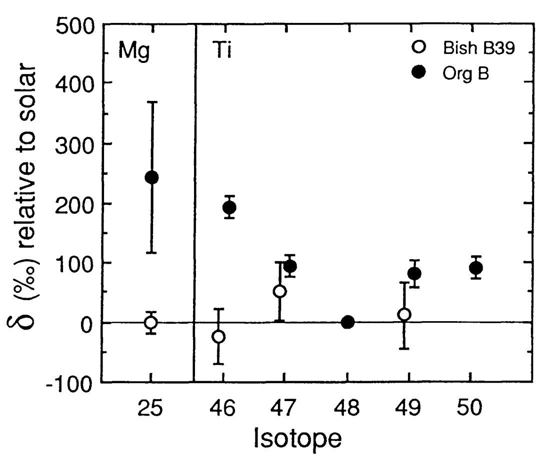

Fig. 1.

material from the He-shell than from the H-shell, assuming no ^{26}Al decay in the envelope. In contrast, the lack of measurable Mg and Ti anomalies in B39 imply little or no He-shell contribution. This indicates that ^{26}Al in B39 was supplied by second dredge-up prior to He-shell ignition and points to a parent star of 4–7 $M_\odot$ [5].

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CHLORINE METASOMATISM AND ELEMENTAL REDISTRIBUTION IN UNEQUILIBRATED ORDINARY CHONDRITES.

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Some Tieschitz chondrules have mesostases partly altered to Na-Al-Cl-rich material [1] similar to the "white matrix" [2] that fills channels between chondrules. Altered mesostases (and white matrix) are enriched in F, Cl, K, Rb, and Ba relative to unaltered mesostases [3]. The alteration is located close to chondrule margins, so the fluids responsible probably came from outside the chondrules. We discuss REE distribution between the three materials as a guide to the process(es) involved. One chondrule in Chainpur and one in Parnallee also have Cl-bearing phases. Their REE contents may be accounted for by closed-system crystallization, but extraneous fluid may be required for the introduction of Cl and Na.

Tieschitz: The REE contents of altered and unaltered mesostases are essentially unfractionated (Fig. 1). The range in five areas of white matrix is from 6× chondritic with small negative Eu anomalies, to 0.8× chondritic with a positive Eu anomaly. Crystallization of REE-poor olivine and/or Ca-poor pyroxene in the chondrules produced mesostases enriched in unfractionated REE. The alteration enriched the mesostases in F, Cl, K, Rb, and Ba, but the REE were unaffected. White matrix outside chondrules, however, shows different degrees of REE depletion, which was more extreme for the HREE, less so for Eu. Variations in REE depletion in the white matrix may result from the scavenging action of randomly distributed phosphate [4] in the interchondrule matrix, but REE do not seem to have been lost from chondrules.

Chainpur: A radiating pyroxene chondrule has two types of altered mesostasis. One resembling sodic scapolite in composition (C(a)[3]) is HREE depleted, the other is nepheline-like and LREE enriched. Both are enriched in Ba. Crystallization of Ca-poor pyroxene followed by some Ca-rich pyroxene (LREE depleted) produced a liquid enriched in REEs, especially the LREEs. The REEs were then distributed between the two types of mesostases, being largely excluded from the scapolite-like type.

Parnallee: Plagioclase (An_{70-87}) coexists with minor nepheline (with 0.9 wt% Cl) in the mesostases of a barred olivine (Fo_{72-76}) chondrule [3]. The feldspar has a positive (Eu/Eu*) anomaly >50 and bulk REEs are below 1.15× chondritic. The nepheline is LREE enriched (La is 11.6 chondritic)

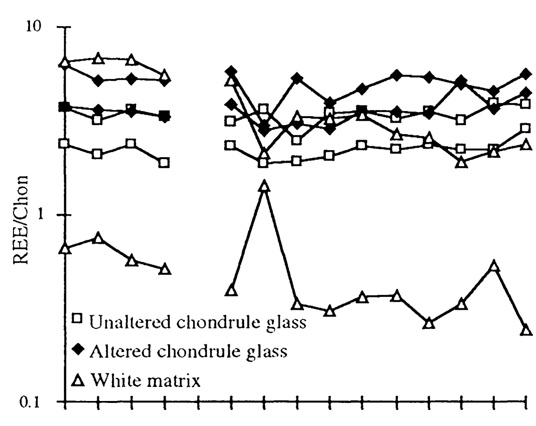

Fig. 1. Tieschitz REE.